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Systematic Model Error and Seasonal Predictability of the Asian Summer Monsoon

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The goals of this paper are to (1) ascertain the ability of atmospheric GCMs to hindcast the summer monsoons of 1987, 1988, and 1993, (2) to determine how well the models represent the dominant modes of subseasonal variability of the 850hPa flow, (3) to determine if the models can represent the strong link between the subseasonal modes of variability and the rainfall, (4) to determine if the models properly project these modes onto interannual timescales, (5) to determine if it is possible to objectively discriminate among the ensemble members to ascertain which members are most reliable.

The results are based upon contributions to the seasonal prediction model intercomparison project (SMIP), which was initiated by the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP). For June-September, ensembles of integrations were performed using observed initial conditions, and observed sea surface temperatures. Here, the results from a 4-member ensemble from the United Kingdom Met Office (UKMO) model are presented for the sake of brevity. The conclusions based on the analysis of this model are consistent with the behaviour of the other models.

EOF analysis of daily 850hPa wind is used to extract the dominant modes of subseasonal variability from the NCEP/NCAR reanalysis (Fig. 1).These modes are also recovered using ECMWF reanalysis (not shown). They correspond almost exactly to those extracted from 40 years of NCEP/NCAR reanalysis, attesting to their robustness for controlling variability over the Asian summer monsoon region (Sperber et al. 2000 [*Quart. J. Roy. Meteorol. Soc.* in press; PCMDI Report No. 56], 1999 [CLIVAR Exchanges No. 14, December 1999]). EOF-1 (Fig. 1a) corresponds to the active phase of the monsoon with the tropical convergence zone (TCZ) being located over the monsoon continental latitudes. It is well simulated by the UKMO model (not shown). EOF-2 (Fig. 1b) is related to EOF-1, and is associated with the initiation of the northward propagation of the TCZ. The model fails to properly capture the flow over East Asia (not shown). EOF-3 (Fig 1c) is a common mode of subseasonal and interannual variability that is most important for controlling the low-level flow and the rainfall over India. In the UKMO model it is represented by EOF-4 (not shown), crudely capturing the anticyclone/cyclone pattern in the vicinity of India seen clearly in EOF-3 from the NCEP/NCAR reanalysis (Fig. 1c). Composite differences of rainfall (not shown) based on days when the principal components exceed +/- 1 standard deviation thresholds confirm that the model modes correspond to the observed modes. Most models were able to capture these modes reasonably well, although the coarser resolution models were the most problematic, failing to capture the strong gradients in the flow.

As discussed in Sperber et al. (1999, 2000) the seasonal mean of each principal component time series gives the projection of that mode onto the interannual variability. The projections of the ensemble members and validation from NCEP/NCAR and ECMWF reanalyses are given in Table 1. Importantly, for these 3 modes the projections from the two reanalyses agree in sign indicating that they

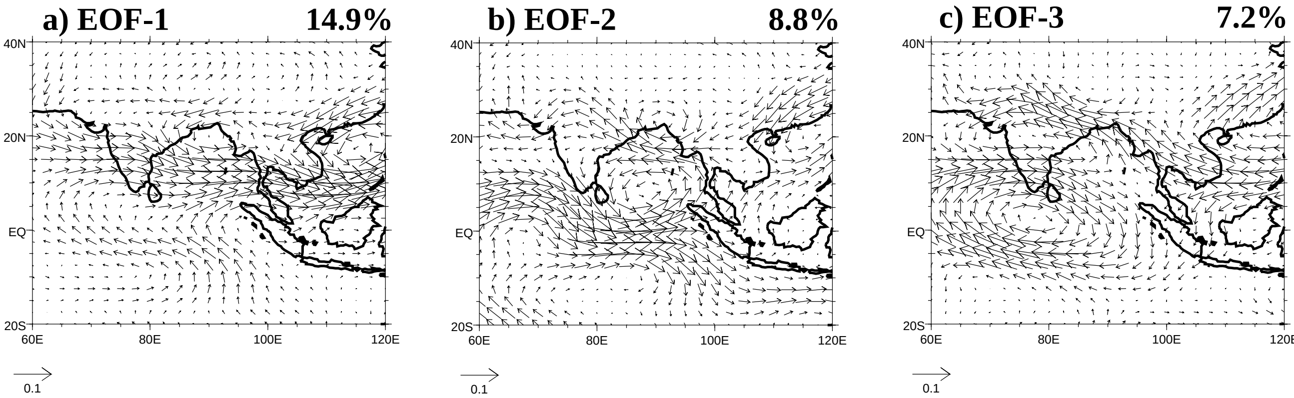

Fig. 1: Results of an empirical orthogonal function analysis of daily 850hPa wind for June-September 1987, 1988 and 1993 using NCEP/NCAR reanalysis. The climatological daily means have been removed prior to the EOF analysis. The percentage variance explained by each mode is also given.

project on to the interannual variability in same way, although the different amplitudes are indicative of observational uncertainty. Those realizations that were able to capture the correct signs of the projections of the first 2 or 3 modes during a given year are shaded.

In 1987 the model was unable to capture the correct projections of all three modes onto the interannual variability, and as such the model failed to even qualitatively capture the precipitation and 850hPa wind anomalies (not shown). Rather the model incorrectly produced enhanced rainfall over India in 1987. This is consistent with the systematic error of this model in that it produces enhanced rainfall over India during El Niño conditions (J. M. Slingo, personal communication, 1999).

In 1988, 3 of 4 members did not properly simulate the projection onto interannual timescales (Table 1). While the model does qualitatively represent the southeasterly anomalies in the vicinity of the monsoon trough (Fig. 2c, 80^{o}E, 20^{o}N) it fails to capture the onshore flow and cyclonic circulation anomalies near the west coast of India, and it overestimates the cyclonic anomalies at the head of the Bay of Bengal seen in the NCEP/NCAR reanalysis (Fig. 2a). Hence the model (Fig. 2d) fails to capture the enhanced rainfall over the whole of the Indian subcontinent, and it overestimates the negative rainfall anomalies over the Bay of Bengal compared to the observed anomalies (Fig. 2b). However, as seen in Table 1, the integration that was run using the 31 May 1988 initial conditions successfully captured the correct sign of the projections of all 3 modes, and as seen in Figs. 2e-f, this member more realistically represents the observed rainfall and 850hPa wind anomalies. In particular, it better represents the orientation of the wind anomalies in the monsoon trough and has a tendency for onshore flow near southern India. Additionally, this member has cyclonic anomalies near the west coast of India, and the cyclonic anomalies over the Bay of Bengal are not as strong relative to the anomalies calculated using all members (Fig. 2c). Consequently, the 31 May 1988 member is more realistic at representing the enhanced rainfall over India and the reduced rainfall over the Bay of Bengal, although it is evident that EOF-1 dominates the seasonal anomaly given its overly strong projection of $\overline{\text{PC-1}}$ (Table 1).

During 1993 three of four members give the proper projections of the subseasonal modes onto the interannual variability, and as a consequence the wind and rainfall anomalies are better captured during this summer (not shown). The 29 May 1993 integration was unable to capture the correct projections onto the interannual variability, and its removal from the ensemble yields further improvement in the wind and rainfall anomalies (not shown).

Table 1 also indicates a systematic error that plagues 5 of the 7 models analyzed in SMIP. Specifically, the models exhibit strong perturbations to the first mode of variability, with most realizations having large positive projections in 1987, and strong negative projections in 1988. This is not in accordance with the observed projections in these 2 years (Table 1) or the results of Sperber et al. (2000) that demonstrated the first mode of variability was chaotic with respect to the phase of ENSO, or strong or weak years of Indian monsoon rainfall based on their analysis of 40 years of NCEP/NCAR reanalysis. This indicates that the models are preferentially exciting the dominant mode in a systematic fashion when in fact this behaviour is not seen in the observations. It is possible that the models are unrealistically teleconnecting this mode to the boundary forcing. That the observed first mode is chaotic severely limits dynamical seasonal predictability of the summer monsoon since random perturbations to this mode may dominate the total seasonal anomaly.

For $\overline{\text{PC-3}}$, the reanalysis results in Table 1 are consistent with the findings of Sperber et al. (1999, 2000), with the mean being negative in 1987 and positive in 1988 (years of weak and strong all-India rainfall respectively). The majority of models fail to establish this relationship further compromising dynamical seasonal predictability of the Asian summer monsoon.

Another error of note is the improper simulation of the rainfall anomalies associated with each of the modes. Thus, even if a model does capture the correct projection of the 850hPa wind, the seasonal prediction of the rainfall anomaly will be incorrect. Furthermore, the errors in the rainfall anomalies associated with each of the modes are consistent with errors in the time-mean rainfall.

Table 1: Seasonal means of the principal components of the daily 850hPa wind for 1987, 1988 and 1993. Those realizations that captured the correct signs of the observed projections during a given year are shaded.

Year/I.C.	Source	$\overline{\text{PC-1}}$	$\overline{\text{PC-2}}$	$\overline{\text{PC-3}}$*
1987	**NCEP**	**-2.5**	**-1.8**	**-14.3**
	ERA	**-1.6**	**-2.4**	**-6.5**
28 May	UKMO	19.2	6.0	1.8
29 May	UKMO	31.9	-5.7	14.0
30 May	UKMO	-8.8	12.0	2.0
31 May	UKMO	23.7	7.4	2.8
1988	**NCEP**	**-7.6**	**-1.3**	**10.8**
	ERA	**-5.9**	**-1.4**	**5.3**
28 May	UKMO	-26.1	-12.0	-2.5
29 May	UKMO	-32.8	0.5	0.6
30 May	UKMO	-27.2	-13.8	-5.7
31 May	UKMO	-18.2	-4.7	8.8
1993	**NCEP**	**10.1**	**3.1**	**3.5**
	ERA	**7.5**	**3.7**	**1.2**
28 May	UKMO	17.7	14.5	-5.9
29 May	UKMO	-11.8	-9.3	-2.0
30 May	UKMO	8.8	3.1	-6.7
31 May	UKMO	23.7	1.9	-7.4

***$\overline{\text{PC-4}}$ from UKMO**

To varying degree the models represent some but not all of the dominant modes of subseasonal variability during the Asian summer monsoon. For the afore-mentioned modes, the models usually represent the subseasonal link between the 850hPa flow and the rainfall. However, in most cases the models do not properly represent the projection of these modes onto the interannual variability. Consequently, the hindcasts are typically poor. When an ensemble member qualitatively represents the seasonal projections of the individual modes, then that member gives a more realistic representation of the observed seasonal anomalies of 850hPa wind and precipitation. The converse is also true. At least 2 possible causes exist for the poor performance of the hindcasts. These include: (1) the strong spin-up due to the initial shock of using observed initial conditions (not shown) which are out of balance with the usual parameter space of the model, and (2) systematic errors of the model climatologies need to be reduced since this is associated with the improper simulation of remote teleconnections.

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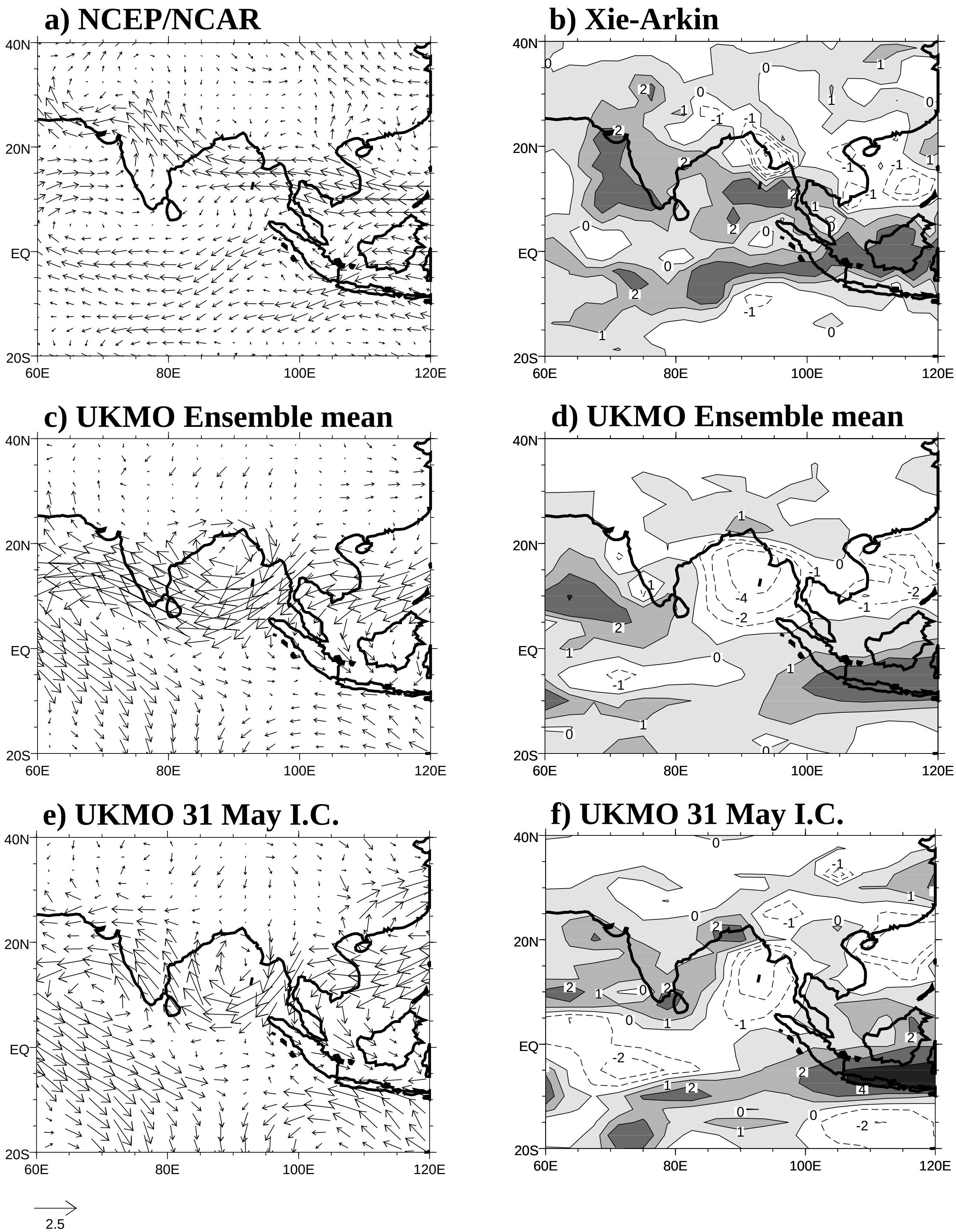

Fig. 2: June-September seasonal mean anomalies for 1988 relative to the climatology for 1987, 1988, and 1993. (a) NCEP/NCAR 850hPa wind (m s^{-1}), (b) Xie and Arkin (1996) rainfall (mm day^{-1}), (c) UKMO 850hPa wind from the full ensemble, (d) as (c) but for rainfall, (e) UKMO 850hPa wind from the 31 May 1988 initial condition integration, (f) as (e) but for rainfall.